

# PATENT ABSTRACTS OF JAPAN

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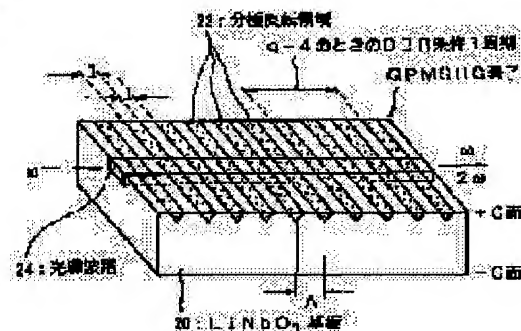
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## (54) SECOND HARMONIC OPTICAL WAVE GENERATION DEVICE

(57)Abstract:

PURPOSE: To acquire a device of high SHG efficiency wherein DBR conditions are relaxed by using an SHG element with specific periodical refractive index distribution structure.

CONSTITUTION: A semiconductor laser as a fundamental wave light source and a quasi-phase matching second harmonic generation(QPMSHG) element are optically coupled to allow the semiconductor laser to perform laser oscillation by using feedback light from the QPMSHG element, and the QPMSHG element is provided with a periodical refraction factor distribution structure along a propagation direction of fundamental wave. In such an SHG device, the periodical refractive index distribution structure is constituted to make a period 1 wherein the refractive index changes along a direction of light propagation satisfy both an equation (1):  $1=(2s-1)\lambda/[4\{N(\lambda/2)-N(\lambda)\}]$  and an equation (2):  $1=(p'/q)\lambda/[4N(\lambda)]$  simultaneously. Here, s and p' are natural numbers, q is a natural number exceeding 2,  $\lambda$  is the wave length of fundamental wave and  $N(\lambda/2)$  and  $N(\lambda)$  are effective refractive index of periodical refractive index distribution structure to second harmonic waves and fundamental waves, respectively.



## LEGAL STATUS

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CLAIMS

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[Claim(s)]

[Claim 1] It has the semiconductor laser as the fundamental-wave light source, and a false phase matching second harmonic generation component. So that said semiconductor laser may carry out laser oscillation of said semiconductor laser and said false phase matching second harmonic generation component using the feedback light from said false phase matching second harmonic generation component In the optical second harmonic generation equipment with which optical coupling has been carried out and said false phase matching second harmonic generation component comes to have periodic refractive-index distribution structure along the propagation direction of a fundamental wave Said periodic refractive-index distribution structure is optical second harmonic generation equipment characterized by being constituted and the period  $l$  from which a refractive index changes along the direction which light spreads becoming so that following the (1) type and (2) types may be satisfied simultaneously.

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \quad \dots (1)$$

$$l = (p'/q) \cdot \lambda / [4N_s(\lambda)] \quad \dots (2)$$

However,  $s$  and  $p'$  show the natural number,  $q$  shows the two or more natural numbers, respectively,  $\lambda$  shows the wavelength of a fundamental wave and  $N(\lambda/2)$  and  $N(\lambda)$  show the effective index of said periodic refractive-index distribution structure over the 2nd higher harmonic and a fundamental wave, respectively.

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DETAILED DESCRIPTION

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[Detailed Description of the Invention]

[0001]

[Industrial Application] This invention relates to the optical second harmonic generation (it is also hereafter called SHG) equipment which makes semiconductor laser (it is also hereafter called LD) the fundamental-wave light source.

[0002]

[Description of the Prior Art] The technique which short-wavelength-izes wavelength of LD which is the small light source in the densification of optical disk memory or the field of an image processing technique recent years especially is searched for strongly. As a technique which short-wavelength-izes wavelength of LD to one half, the equipment for realizing various SHG approaches and them is proposed conventionally. The artificer who starts this application also in it has proposed the approach of specifying the oscillation wavelength of LD stably on the wavelength with which it is satisfied of false phase matching (it is also hereafter called QPM) conditions with feedback from an SHG component, in Japanese Patent Application No. No. 51930 [ three to ]. Hereafter, this approach is called a self-false phase matching method or the S-QPM method.

[0003] S-QPM for realizing this S-QPM method with reference to a drawing, in order to make an understanding of invention concerning this application easy hereafter SHG equipment (self-false phase matching light second harmonic generation equipment) is explained briefly. Drawing 4 is S-QPM. It is the schematic diagram with which explanation of SHG equipment is presented.

[0004] This S-QPM The component which constitutes SHG equipment is LiNbO<sub>3</sub> which is a nonlinear optical crystal. It has a substrate 10 and the optical waveguide 12 formed in that front face, and the polarization reversal field 14 is periodically formed into this optical waveguide 12. It can be considered that these polarization reversal field 14 will form the diffraction grating along the direction of a photoconductive wave if the optical waveguide 12 whole is seen, since the refractive index is slightly higher than the remainder (non-polarization reversal field) 16 of optical waveguide 12. Therefore, these polarization reversal field 14 and the non-polarization reversal field 16 will form periodic refractive-index distribution structure.

[0005] Here, if it constitutes so that an external optical resonator may be formed with semiconductor laser (LD) and a component, the laser oscillation by which LD was stabilized by optical feedback from periodic refractive-index distribution structure can be started.

[0006] and S-QPM SHG -- equipment -- a component -- \*\*\*\* -- optical waveguide -- 12 -- inside -- a refractive index -- changing -- a period --  $\lambda$  -- namely, -- polarization -- reversal -- a field -- formation -- a period --  $\lambda$  -- QPM -- conditions -- being shown -- the following -- ( -- one -- ) -- a formula -- Bragg reflection (DBR) -- conditions -- being shown -- the following -- ( -- three -- ) -- a formula -- simultaneous -- being satisfied -- as -- setting up -- having had -- periodic -- a refractive index -- distribution -- structure -- preparing -- \*\*\*\* .

[0007]

$$l = (2s-1) \cdot \left[ 4 \left\{ N(\lambda/2) - N(\lambda) \right\} \right] \dots\dots (1)$$

$$L = p \cdot \lambda / \{ 4N_s(\lambda) \} \dots\dots\dots (3)$$

However, l shows each dimension ( $l = \lambda/2$ ) along the propagation of the light of a polarization reversal field and a non-polarization reversal field, s and p show the natural number, respectively and  $N(\lambda/2)$  and  $N(\lambda)$  show the effective index of the polarization reversal field to the 2nd higher harmonic and a fundamental wave, respectively.

[0008] If the component is considered as such a configuration, the feedback light from periodic refractive-index distribution structure to LD will increase. For this reason, laser oscillation happens and QPM conditions are further satisfied by this feedback light. Consequently, the optical reinforcement of the 2nd higher harmonic increases for every coherent length, and further, since the light ( $2\omega$ ) of this 2nd higher harmonic passes refractive-index distribution structure, outgoing radiation of it will be carried out by high power from a QPM component.

[0009] Thus, S-QPM In SHG equipment, achievement of high SHG effectiveness is attained theoretically.

[0010]

[Problem(s) to be Solved by the Invention] However, conventional S-QPM In SHG equipment, it is difficult to satisfy simultaneously above-mentioned (1) type and (2) types to accuracy. This is because a high precision is required of the dimension of the period of refractive-index distribution structure in order to satisfy QPM conditions and DBR conditions. There was a problem that there was a limit (at most submicrometer extent) in the precision of a period producible [ with the technique of the conventional photolithography ], and the produced own dimension of SHG equipment will change with temperature changes to this precision.

[0011] Here, the count result of the relation between the dimension of the period of periodic refractive-index distribution structure and the conversion efficiency of a QPM component is shown as an example of the precision required of drawing 2 . The axis of abscissa of the graph of drawing 2 expresses the period of the periodic polarization reversal structure as periodic refractive-index distribution structure, and the axis of ordinate expresses SHG conversion efficiency with the relative value of \*\*\*\* 2 higher-harmonic reinforcement (SH). In count, the wavelength of light calculated bases as 1.327 micrometers, 6.5 micrometers of coherence length, ambient temperature 300K, and 2mm (equivalent to about 300 periods) of component length. It turns out that the half-value width which is one rule of thumb of the precision demanded in order to satisfy QPM conditions from the graph of drawing 2 is about 39nm. This half-value width serves as a rule of thumb of the tolerance of the precision of the dimension of the period as QPM.

[0012] Next, the count result of the relation between the dimension of a period and the reflection factor of DBR is shown in drawing 3 . The axis of abscissa of the graph of drawing 3 expresses the period of polarization reversal structure, and the axis of ordinate expresses the reflection factor of DBR. It turns out that the half-value width which is one rule of thumb of the precision demanded in order to satisfy DBR conditions from drawing 3 is about 0.56nm. This half-value width serves as a rule of thumb of the precision required of the dimension of the period as DBR, i.e., tolerance. In this example of count, the tolerance of DBR conditions is about 1 of tolerance of QPM conditions/70.

[0013] Although it is only an example, compared with the precision demanded in order to fulfill QPM conditions, as for the half-value width shown in drawing 2 and drawing 3 , respectively, it turns out that the precision demanded in order to satisfy DBR conditions is far high, i.e., tolerance is far small. Therefore, S-QPM In SHG equipment, it turns out that it depends for SHG effectiveness on the tolerance of DBR conditions rather than QPM conditions.

[0014] On the other hand, it is above-mentioned S-QPM. In order to satisfy the conditions for realizing SHG, adjusting the refractive index of a crystal using the fine adjustment technique of temperature control is also considered. However, it is S-QPM when the configuration for these

temperature control etc. is included. Fine adjustment of SHG equipment not only becomes complicated technically, but will cause lifting of the production cost of equipment. S-QPM When putting SHG equipment in practical use, it is important to make a production cost low.

[0015] Therefore, the object of this invention is S-QPM which eased DBR conditions. It is in offering SHG equipment.

[0016]

[Means for Solving the Problem] In order to aim at achievement of this object, according to the optical second harmonic generation equipment of this invention It has the semiconductor laser (LD) as the fundamental-wave light source, and a false phase matching second harmonic generation component (QPM SHG component). LD and QPM About an SHG component, LD is QPM. So that laser oscillation may be carried out using the feedback light from an SHG component Optical coupling has been carried out and it is QPM. In the optical second harmonic generation equipment with which an SHG component comes to have periodic refractive-index part structure along the propagation direction of a fundamental wave periodic refractive-index distribution structure It is characterized by being constituted and the period  $l$  from which a refractive index changes along the direction which light spreads becoming so that following the (1) type and (2) types may be satisfied simultaneously.

[0017]

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots (1)$$

$$l = (p'/q) \cdot \lambda / [4N_s(\lambda)] \dots (2)$$

However,  $s$  and  $p'$  show the natural number,  $q$  shows the two or more natural numbers, respectively,  $\lambda$  shows the wavelength of a fundamental wave and  $N(\lambda/2)$  and  $N(\lambda)$  show the effective index of the periodic refractive-index distribution structure over the 2nd higher harmonic and a fundamental wave, respectively.

[0018]

[Function] According to the optical second harmonic generation equipment of this invention, it sets to self-false phase matching light second harmonic generation (S-QPM SHG) equipment, and is QPM. The periodic refractive-index distribution structure of an SHG component is constituted so that the period  $l$  from which a refractive index changes along the direction which light spreads may satisfy simultaneously following the (1) type and (2) types.

[0019]

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots (1)$$

$$l = (p'/q) \cdot \lambda / [4N_s(\lambda)] \dots (2)$$

(However,  $s$  and  $p'$  show the natural number,  $q$  shows the two or more natural numbers, respectively,  $\lambda$  shows the wavelength of a fundamental wave and  $N(\lambda/2)$  and  $N(\lambda)$  show the effective index of the periodic refractive-index distribution structure over the 2nd higher harmonic and a fundamental wave, respectively.)

Thus, if constituted, since the periodic polarization reversal structure of satisfying DBR conditions will turn into super-period structure, DBR conditions can be eased. Consequently, S-QPM with high SHG effectiveness SHG equipment can be obtained more easily than before.

[0020] Parameter  $M$  is introduced and it explains natural number  $p'$  which satisfies hereafter (2) types mentioned above, and that  $q$  can be set up.  $M$  is expressed with the following formula (4) when the number of the periods in the polarization reversal structure covering all the component length when setting component length to  $L$  is set to  $M$ .

[0021]

$$M = pL/l = L / [\lambda / (4N_s(\lambda))] \dots (4)$$

By the way,  $M$  is also the number of the periods of Bragg reflection structure. Furthermore, it is known that the half-value width used as the rule of thumb of the tolerance of Bragg reflection conditions (DBR conditions) is mostly in inverse proportion to the value of this  $M$ . Therefore, what is necessary is just to make this  $M$  small, in order to make large half-value width of black reflective conditions. (4) Since  $l$  in a formula is a requirement for satisfying QPM conditions, it cannot change the value of  $l$  itself. Then, as shown in the following (2) types from (3) types which mentioned DBR conditions above, it changes.

[0022]

$$l = (p'/q) \cdot \lambda / [4N_s(\lambda)] \dots (2)$$

In this case, several  $M'$  of the period of effectual Bragg reflection structure will be  $1/q$  time the  $M$ , as shown in (5) types below. In connection with this, the half-value width of Bragg reflection conditions becomes about  $q$  times. consequently, DBR conditions are eased  $q$  times -- things -- \*\*

[0023]

$$M' = M/q \dots (5)$$

Therefore, although one period of the polarization reversal structure of satisfying QPM conditions is with a die length of  $2l$ . which consisted of one polarization reversal field (die-length  $l$ ) and one non-polarization reversal field (die-length  $l$ ) as when polarization reversal structure is established so that (1) type and (2) types may be satisfied simultaneously On the other hand, one period has the so-called superstructure (structure where two or more periodic structures can be grasped in one periodic structure) of the die length  $2(ql)$  which consists of every  $q$  polarization reversal fields and a non-polarization reversal field, respectively as Bragg reflection structure. Namely, this S-QPM  $q$  period of QPM conditions will be satisfied with SHG equipment of one period of DBR conditions reflecting above-mentioned (5) types.

[0024] Next, it is shown that the integer  $q$  for which (1) type mentioned above and (2) types can be satisfied simultaneously exists. Here, in order to avoid \*\*\*\*, the case of  $s=1$  is explained. In  $s=1$ , existence of  $q$  can be proved similarly. the case of  $q=1$ , i.e., conventional S-QPM, wavelength  $\lambda$  which has a fundamental wave in SHG equipment --  $1<\lambda'<\lambda$  -- in  $\lambda+1$ , (1) type which  $\lambda'$  mentioned above, and <(3) type are filled simultaneously.

[0025]

$$L = \lambda - 1 / [4 \{N(\lambda - 1/2)\}] = (p-1) \lambda - 1 / [4N(\lambda - 1)]$$

$$= \lambda' / [4 \{N(\lambda'/2)\}] = p \lambda' / [4N_s(\lambda')]$$

$$= \lambda + 1 / [4 \{N(\lambda + 1/2)\}] = (p+1) \lambda + 1 / [4N(\lambda + 1)]$$

Here, it proves that natural number  $p'$  which fills the following (6) types exists to the natural number which becomes  $q \geq 2$ .

[0026]

$$p-1 < p'/q < p+1 \dots (6)$$

$$\text{That is, each side is } q \text{ Doubled and it is } pq-q < p' < pq+q \dots (7)$$

What is necessary is just to show that  $p'$  of the \*\*\*\*\* natural number exists.

[0027] By the way, the  $2q-1$  piece natural number exists in from  $pq-q$  before  $pq+q$  of (7) types. Therefore, it turns out that  $p'$  which fills (7) types exists. Therefore, it turns out natural number  $p'$  which satisfies (2) types, and that  $q$  can be set up.

[0028]

[Example] Hereafter, with reference to a drawing, the example of the optical second harmonic generation equipment of this invention is explained. In addition, drawing referred to below has shown the magnitude, the configuration, and arrangement relation of each constituent roughly to extent which can understand this invention. Therefore, this invention of be [ it / what is limited to the example of a graphic display ] is clear.

[0029] Drawing 1 is QPM which is the explanatory view with which explanation of the example of the optical second harmonic generation equipment of this invention is presented, and constitutes equipment. It is the perspective view of an SHG component. This example shows the structure when being referred to as  $q=4$ .

[0030] The optical second harmonic generation equipment of this invention is equipped with the semiconductor laser (not shown) as the fundamental-wave light source, and a false phase matching second harmonic generation component (QPM SHG component), and is LD and QPM. About an SHG component, LD is QPM. Optical coupling has been carried out so that laser oscillation may be carried out using the feedback light from an SHG component. QPM The SHG component is equipped with periodic refractive-index part structure along the propagation direction of a fundamental wave.

[0031] for this reason — the optical second harmonic generation equipment of this example — QPM as an SHG component (it is also only hereafter called a component) — LiNbO<sub>3</sub> +C side of a substrate 20 — Ti (titanium) — being periodic (period of  $\lambda = 2l$ ) — it has the periodic polarization reversal structure which was diffused and formed the polarization reversal field 22. Moreover, optical waveguide 24 is formed with the proton exchange buffering method (Li<sup>+</sup>-H<sup>+</sup> exchange buffering method) so that it may intersect perpendicularly with this periodic polarization reversal structure.

[0032] The periodic polarization reversal structure which is the periodic refractive-index distribution structure where this optical waveguide 22 was met is constituted so that the period  $l$  from which a refractive index changes along the direction which light spreads may satisfy simultaneously following the (1) type and (2) types.

[0033]

$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}]$  ..... (1)

$l = (p'/q) \cdot \lambda / [4N_s(\lambda)]$  ..... (2)

However,  $s$  and  $p'$  show the natural number, respectively,  $q$  shows the two or more natural numbers,  $\lambda$  shows the wavelength of a fundamental wave and  $N(\lambda/2)$  and  $N(\lambda)$  show the effective index of the periodic refractive-index distribution structure over the 2nd higher harmonic and a fundamental wave, respectively.

[0034] One period of the polarization reversal structure where it is satisfied with this example of QPM conditions as  $q = 4$  With a die length of  $2l$ . ( $=\lambda$ ) which consisted of one polarization reversal field (die-length  $l$ ) and one non-polarization reversal field (die-length  $l$ ) as \*\*. On the other hand, one period as Bragg reflection structure is die-length  $2 \times (4l) = 4\lambda$  which consists of every four polarization reversal fields and a non-polarization reversal field, respectively, and has the so-called superstructure. Therefore, four periods of QPM conditions are satisfied with this example of one period of DBR conditions. For this reason, the tolerance of the precision demanded in order to satisfy DBR conditions will be eased 4 times at the time of being referred to as  $q = 1$ .

[0035] Although the example mentioned above explained the case where used the specific ingredient and this invention was formed on condition that specification, this invention can perform many modification and deformation. For example, at the example mentioned above, it is LiNbO<sub>3</sub>. Although the substrate 20 was used, by this invention, it is KTiOPO<sub>4</sub>, for example. A substrate (KTP) 26 can also be used. Moreover, QPM which has the structure of distributing periodically over a substrate the high refractive-index field 22 where a refractive index is higher than a substrate, and making it spreading a fundamental wave in accordance with this distribution in this invention as shown in drawing 5 although the optical waveguide 24 which intersects perpendicularly with polarization reversal structure was formed in the example mentioned above It is good also as an SHG component.

[0036]

[Effect of the Invention] Since periodic polarization reversal structure of satisfying DBR conditions was made into super-period structure according to the optical second harmonic generation equipment of this invention, DBR conditions can be eased. Consequently, S-QPM with high SHG effectiveness SHG equipment can be obtained more easily than before.

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DESCRIPTION OF DRAWINGS

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[Brief Description of the Drawings]

[Drawing 1] S-QPM of this invention QPM of SHG equipment It is the perspective view with which explanation of an SHG component is presented.

[Drawing 2] It is the graph which shows the count result of the relation between the period of periodic refractive-index distribution structure, and the conversion efficiency of QPM.

[Drawing 3] It is the graph which shows the count result of the relation between the period of periodic refractive-index distribution structure, and the reflection factor of DBR.

[Drawing 4] Conventional S-QPM QPM of SHG equipment It is the schematic diagram with which explanation of an SHG component is presented.

[Drawing 5] The conventional QPM using a KTP substrate It is the perspective view with which explanation of the modification of an SHG component is presented.

[Description of Notations]

10: LiNbO<sub>3</sub> Substrate

12: Optical waveguide

14: Polarization reversal field

16: Non-polarization reversal field

20: LiNbO<sub>3</sub> Substrate

22: Polarization reversal field (high refractive-index field)

24: Optical waveguide

26: KTP substrate

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[Translation done.]

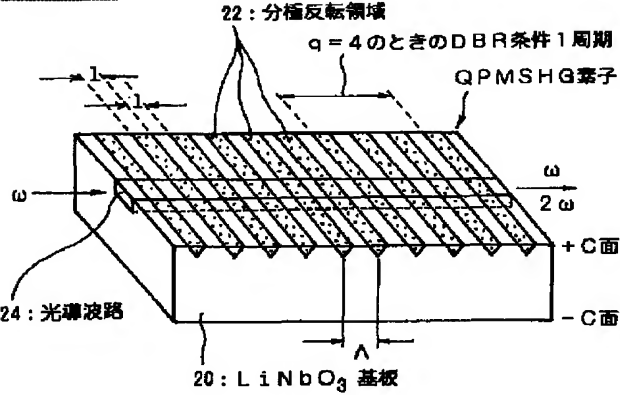
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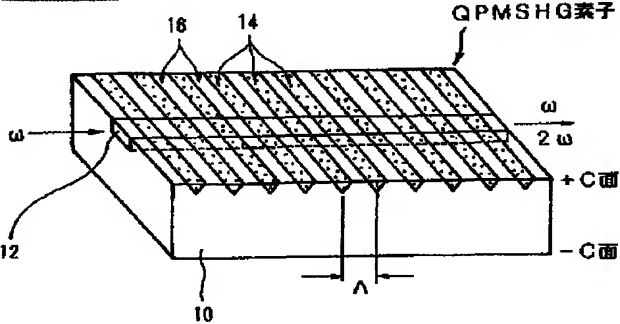
DRAWINGS

[Drawing 1]



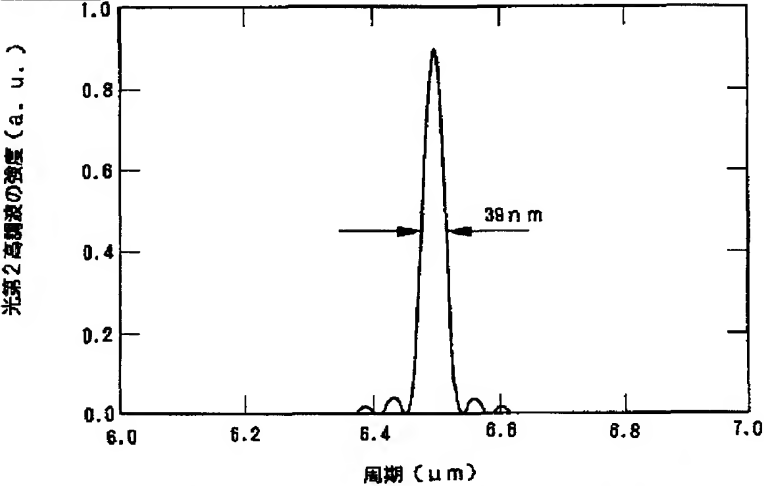
実施例のQPM SHG素子

[Drawing 4]



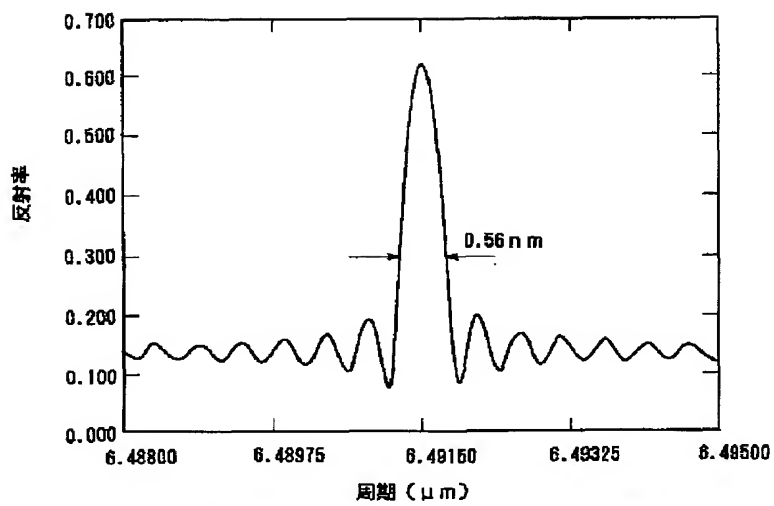
従来LiNbO<sub>3</sub> によるQPM SHG素子

[Drawing 2]



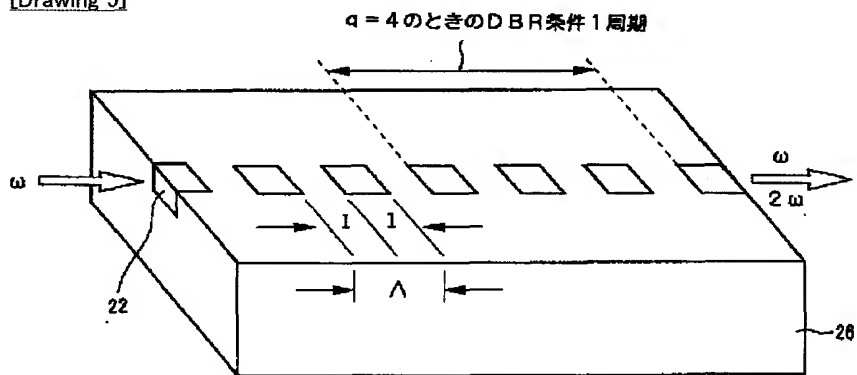
屈折率分布構造の周期とQPM素子の変換効率との関係

[Drawing 3]



屈折率分布構造の周期とDBRの反射率との関係

[Drawing 5]



変形例

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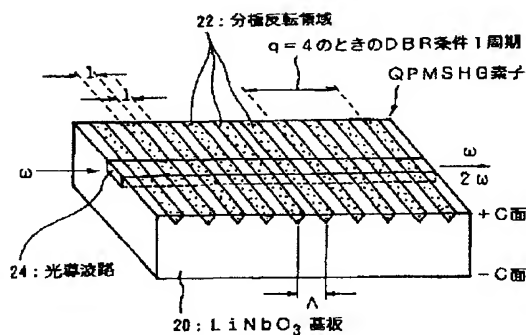
(74) 代理人 弁理士 大垣 孝

(54) 【発明の名称】 光第2高調波発生装置

(57) 【要約】

【目的】 ブラッグ反射条件を緩和した擬似位相整合光第2高調波発生装置を提供すること。

【構成】 この実施例では、 $q=4$ として、QPM条件を満足する分極反転構造の1周期は、1つの分極反転領域(長さ1)と1つの非分極反転領域(長さ1)とから構成された長さ2( $=\Lambda$ )のままであるが、一方、ブラッグ反射構造としての1周期はそれぞれ4つつの分極反転領域および非分極反転領域から構成される長さ $2 \times (41) = 4\Lambda$ であり、いわゆる超格子構造となっている。従って、この実施例ではQPM条件の4周期がDBR条件の1周期を満足するようになっている。



実施例のQPM SHG素子

## 【特許請求の範囲】

【請求項1】 基本波光源としての半導体レーザと、擬似位相整合第2高調波発生素子とを具備、前記半導体レーザと前記擬似位相整合第2高調波発生素子とを、前記半導体レーザが前記擬似位相整合第2高調波発生素子からの帰還光を利用してレーザ発振するように、光結合させてあり、

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = (p' / q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

但し、sおよびp'はそれぞれ自然数、qは2以上の自然数を示し、λは基本波の波長を示し、N(λ/2)およびN(λ)はそれぞれ第2高調波および基本波に対する前記周期的屈折率分布構造の実効屈折率を示す。

## 【発明の詳細な説明】

## 【0001】

【産業上の利用分野】この発明は、半導体レーザ（以下、LDとも称する）を基本波光源とする光第2高調波発生（以下、SHGとも称する）装置に関する。

## 【0002】

【従来の技術】近年、特に光ディスクメモリの高密度化や画像処理技術の分野で、小型な光源であるLDの波長を短波長化する技術が強く求められている。LDの波長を1/2に短波長化する技術として、従来、様々なSHG方法およびそれを実現するための装置が提案されている。その中でも、この出願に係る発明者は特願平3-51930号において、LDの発振波長をSHG素子からの帰還によって擬似位相整合（以下、QPMとも称する）条件を満足する波長で安定的に規定する方法を提案している。以下、この方法を自己擬似位相整合法またはS-QPM法と称する。

【0003】以下、この出願に係る発明の理解を容易にするために、図面を参照して、このS-QPM法を実現するためのS-QPM SHG装置（自己擬似位相整合※

$$l = (2s-1) \cdot [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = p \cdot \lambda / \{4N(\lambda)\} \dots\dots (3)$$

但し、lは分極反転領域および非分極反転領域の光の伝播方向に沿ったそれぞれの寸法（ $l = \Lambda/2$ ）を示し、s、pはそれぞれ自然数を示し、N(λ/2)およびN(λ)は、それぞれ第2高調波および基本波に対する分極反転領域の実効屈折率を示している。

【0008】素子をこのような構成としておけば、周期的屈折率分布構造からLDへの帰還光が多くなる。このため、この帰還光によってレーザ発振が起こり、さらに、QPM条件が満足される。その結果、コヒーレント長毎に第2高調波の光強度が増大し、さらに、この第2高調波の光（2ω）は屈折率分布構造を通過していくのでQPM素子から高出力で出射されることになる。

【0009】このように、S-QPM SHG装置においては、理論的には高いSHG効率の達成が可能となる。

\*前記擬似位相整合第2高調波発生素子は基本波の伝搬方向に沿って周期的屈折率分布構造を具備する光第2高調波発生装置において、前記周期的屈折率分布構造は、光の伝播する方向に沿って屈折率が変化する周期lが下記（1）式および（2）式を同時に満足するように構成されてなることを特徴とする光第2高調波発生装置。

10※光第2高調波発生装置）について簡単に説明する。図4は、S-QPM SHG装置の説明に供する概略図である。

【0004】このS-QPM SHG装置を構成する素子は、非線形光学結晶であるLiNbO<sub>3</sub>基板10とその表面に形成した光導波路12とを具備しており、この光導波路12中に周期的に分極反転領域14が形成されている。これら分極反転領域14は、光導波路12の残部（非分極反転領域）16よりは屈折率が僅かに高いので、光導波路12全体を見ると、光導波方向に沿って屈折格子を形成しているとみなすことができる。従って、これら分極反転領域14および非分極反転領域16が周期的屈折率分布構造を形成することになる。

【0005】ここで、半導体レーザ（LD）と素子とで外部光共振器を形成するように構成すれば、周期的屈折率分布構造からの光帰還によってLDの安定したレーザ発振を起こすことができる。

【0006】そして、S-QPM SHG装置の素子では、光導波路12中の屈折率の変化する周期Λ、即ち、分極反転領域の形成周期Λが、QPM条件を示す下記の（1）式と、ブラッグ反射（DBR）条件を示す下記の（3）式とを同時に満足するように設定された周期的屈折率分布構造を設けている。

## 【0007】

$$l = (2s-1) \cdot [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = p \cdot \lambda / \{4N(\lambda)\} \dots\dots (3)$$

## 【0010】

【発明が解決しようとする課題】しかしながら、従来のS-QPM SHG装置においては、上述の（1）式および（2）式を同時に正確に満足させることは、困難である。これは、QPM条件およびDBR条件を満足させるために、屈折率分布構造の周期の寸法に高い精度が要求されるためである。この精度に対して、従来のフォトリソグラフィの技術によって作製できる周期の精度には限度（せいぜいサブマイクロメートル程度）があり、また、作製したSHG装置自身の寸法が温度変化によって変化してしまうという問題があった。

【0011】ここで、図2に、要求される精度の一例として、周期的屈折率分布構造の周期の寸法とQPM素子の変換効率との関係の計算結果を示す。図2のグラフの横軸は、周期的屈折率分布構造としての周期的分極反転

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構造の周期を表し、縦軸は、SHG変換効率を光第2高調波強度(SH)の相対値で表している。計算にあたっては、基本は光の波長が $1.327\mu\text{m}$ 、コヒーレンス長 $6.5\mu\text{m}$ 、雰囲気温度 $300\text{K}$ 、素子長 $2\text{mm}$ (約300周期に相当)として計算した。図2のグラフからQPM条件を満足させるために要求される精度の一つの目安である半値幅が約 $39\text{nm}$ であることがわかる。この半値幅がQPMとしての周期の寸法の精度の許容度の目安となる。

【0012】次に、図3に周期の寸法とDBRの反射率との関係の計算結果を示す。図3のグラフの横軸は分極反転構造の周期を表し、縦軸はDBRの反射率を表している。図3からDBR条件を満足させるために要求される精度の一つの目安である半値幅が約 $0.56\text{nm}$ であることがわかる。この半値幅がDBRとしての周期の寸法に要求される精度、すなわち許容度の目安となる。この計算例では、DBR条件の許容度はQPM条件の許容度の約 $1/70$ である。

【0013】図2および図3にそれぞれ示した半値幅は一例にすぎないが、QPM条件を満たすために要求される精度に比べて、DBR条件を満足するために要求される精度がはるかに高いこと、すなわち許容度がはるかに小さいことがわかる。従って、S-QPM SHG装置において、SHG効率はQPM条件よりもDBR条件の許容度に依存することがわかる。

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = (p'/q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

但し、 $s$ および $p'$ はそれぞれ自然数、 $q$ は2以上の自然数を示し、 $\lambda$ は基本波の波長を示し、 $N(\lambda/2)$ および $N(\lambda)$ はそれぞれ第2高調波および基本波に対する周期的屈折率分布構造の実効屈折率を示す。

【0018】

【作用】この発明の光第2高調波発生装置によれば、自※

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = (p'/q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

(但し、 $s$ および $p'$ はそれぞれ自然数、 $q$ は2以上の自然数を示し、 $\lambda$ は基本波の波長を示し、 $N(\lambda/2)$ および $N(\lambda)$ はそれぞれ第2高調波および基本波に対する周期的屈折率分布構造の実効屈折率を示す。)

このように構成すると、DBR条件を満足する周期的分極反転構造は超周期構造となるので、DBR条件を緩和することができる。その結果、SHG効率の高いS-QPM SHG装置を従来よりも容易に得ることができ★

$$M = pL/l = L / \{\lambda / (4N(\lambda))\} \dots\dots (4)$$

ところで、 $M$ はブラッグ反射構造の周期の数でもある。さらに、ブラッグ反射条件(DBR条件)の許容範囲の目安となる半値幅は、この $M$ の値にはほぼ反比例することが知られている。従って、ブラッグ反射条件の半値幅を広くするためには、この $M$ を小さくすれば良い。(4)

$$l = (p'/q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

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\*【0014】一方、上記S-QPM SHGを実現するための条件を満足させるために、温度制御といった微調整技術を用いて結晶の屈折率を調整することも考えられる。しかし、これら温度制御等のための構成を含めるとS-QPM SHG装置の微調整が技術的に煩雑になるだけでなく、装置の生産コストの上昇を招くことになる。S-QPM SHG装置を実用化する上では、生産コストを低くすることが重要である。

【0015】従って、この発明の目的は、DBR条件を緩和したS-QPM SHG装置を提供することにある。

【0016】

【課題を解決するための手段】この目的の達成を図るため、この発明の光第2高調波発生装置によれば、基本波光源としての半導体レーザ(LD)と、擬似位相整合第2高調波発生素子(QPM SHG素子)とを具え、LDとQPM SHG素子とを、LDがQPM SHG素子からの帰還光を利用してレーザ発振するように、光結合させてあり、QPM SHG素子は基本波の伝搬方向に沿って周期的屈折率分構造を具えてなる光第2高調波発生装置において、周期的屈折率分布構造は、光の伝播する方向に沿って屈折率が変化する周期 $l$ が下記(1)式および(2)式を同時に満足するように構成されてなることを特徴とする。

【0017】

※已擬似位相整合光第2高調波発生(S-QPM SHG)装置において、QPM SHG素子の周期的屈折率分布構造は、光の伝播する方向に沿って屈折率が変化する周期 $l$ が下記(1)式および(2)式を同時に満足するように構成してある。

【0019】

$$l = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots\dots (1)$$

$$l = (p'/q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

★る。

【0020】以下、上述した(2)式を満足する自然数 $p'$ 、 $q$ を設定できることを、パラメータ $M$ を導入して説明する。素子長を $L$ としたときの全素子長にわたる分極反転構造の中の周期の数を $M$ とすると、 $M$ は下記の式(4)で表される。

【0021】

$$M = pL/l = L / \{\lambda / (4N(\lambda))\} \dots\dots (4)$$

式中の $l$ は、QPM条件を満足させるための必要条件であるから $l$ の値そのものを変えることはできない。そこで、DBR条件を上述した(3)式から下記の(2)式に示すように変える。

【0022】

$$l = (p'/q) \cdot \lambda / \{4N(\lambda)\} \dots\dots (2)$$

この場合、実効的なブラッグ反射構造の周期の数 $M'$ は下記に(5)式で示すように $M$ の $1/q$ 倍となる。これに伴い、ブラッグ反射条件の半値幅はほぼ $q$ 倍となる。\*

$$M' = M/q \dots \dots \dots (5)$$

従って、(1)式と(2)式とを同時に満足させるように分極反転構造を設けた場合、QPM条件を満足する分極反転構造の1周期は、1つの分極反転領域(長さ $l$ )と1つの非分極反転領域(長さ $l$ )とから構成された長さ $2l$ のままであるが、一方、ブラッグ反射構造として1周期は、それぞれ $q$ 個ずつの分極反転領域および非分極反転領域から構成される長さ $2(ql)$ のいわゆる超格子構造(1つの周期的構造の中に複数の周期的構造を見てとれる構造)となっている。即ち、このS-QPM SHG装置では、上述の(5)式を反映して、QPM条件の $q$ 周期がDBR条件の1周期を満足することになす

$$\begin{aligned} 1 &= \lambda_{-1} / [4 \{N(\lambda_{-1}/2)\}] = (p-1)\lambda_{-1} / \{4N(\lambda_{-1})\} \\ &= \lambda' / [4 \{N(\lambda'/2)\}] = p\lambda' / \{4N(\lambda')\} \\ &= \lambda_{+1} / [4 \{N(\lambda_{+1}/2)\}] = (p+1)\lambda_{+1} / \{4N(\lambda_{+1})\} \end{aligned}$$

ここで、 $q \geq 2$ なる自然数に対して、下記の(6)式を満たす自然数 $p'$ が存在することを証明する。★20

$$p-1 < p' / q < p+1 \dots \dots \dots (6)$$

即ち、各辺を $q$ 倍して

$$pq - q < p' < pq + q \dots \dots \dots (7)$$

を満たす自然数の $p'$ が存在することを示せば良い。  
【0027】ところで、(7)式の $pq - q$ から $pq + q$ までの間には $2q - 1$ 個の自然数が存在する。よって、(7)式を満たす $p'$ が存在することがわかる。従って、(2)式を満足する様な自然数 $p'$ 、 $q$ を設定できることがわかる。

【0028】

【実施例】以下、図面を参照して、この発明の光第2高調波発生装置の実施例について説明する。尚、以下に参照する図は、この発明が理解できる程度に、各構成成分の大きさ、形状および配置関係を概略的に示してあるにすぎない。従って、この発明は、図示例に限定されるものでないことは明らかである。

【0029】図1は、この発明の光第2高調波発生装置の実施例の説明に供する説明図であり、装置を構成するQPM SHG素子の斜視図である。この実施例では、 $q=4$ としたときの構造を示している。

【0030】この発明の光第2高調波発生装置は、基本波光源としての半導体レーザ(図示せず)と、擬似位相☆

$$1 = (2s-1) \cdot \lambda / [4 \{N(\lambda/2) - N(\lambda)\}] \dots \dots \dots (1)$$

$$1 = (p' / q) \cdot \lambda / \{4N(\lambda)\} \dots \dots \dots (2)$$

但し、 $s$ および $p'$ はそれぞれ自然数を示し、 $q$ は2以上の自然数を示し、 $\lambda$ は基本波の波長を示し、 $N(\lambda/2)$ および $N(\lambda)$ はそれぞれ第2高調波および基本波に対する周期的屈折率分布構造の実効屈折率を示す。

【0034】この実施例では、 $q=4$ として、QPM条件を満足する分極反転構造の1周期は、1つの分極反転

\*その結果、DBR条件が $q$ 倍に緩和されることとなる。  
【0023】

※る。

【0024】次に、上述した(1)式と(2)式を同時に満足させることができる整数 $q$ が存在することを示す。ここでは、煩雑を避けるため $s=1$ の場合について説明する。 $s \neq 1$ の場合も同様に $q$ の存在を証明することができる。 $q=1$ の場合、即ち、従来のS-QPM SHG装置においては、基本波のある波長 $\lambda_{-1} < \lambda' < \lambda_{+1}$ において、 $\lambda'$ が上述した(1)式と(3)式とを同時に満たす。

【0025】

★【0026】

☆整合第2高調波発生素子(QPM SHG素子)とを具えており、LDとQPM SHG素子とを、LDがQPM SHG素子からの帰還光を利用してレーザ発振するように、光結合させてある。QPM SHG素子は基本波の伝搬方向に沿って周期的屈折率分構造を具えている。

【0031】このため、この実施例の光第2高調波発生装置では、QPM SHG素子(以下、単に素子とも称する)として、LiNbO<sub>3</sub>基板20の+C面にTi(チタン)を周期的(周期 $\Lambda=2l$ )に拡散させて分極反転領域22を形成した周期的分極反転構造を具えている。また、この周期的分極反転構造と直交するように、プロトン交換法(Li<sup>+</sup>-H<sup>+</sup>交換法)により、光導波路24が形成してある。

【0032】この光導波路22に沿った周期的屈折率分布構造である周期的分極反転構造は、光の伝播する方向に沿って屈折率が変化する周期 $l$ が下記(1)式および(2)式を同時に満足するように構成されている。

【0033】

領域(長さ $l$ )と1つの非分極反転領域(長さ $l$ )とから構成された長さ $2l (= \Lambda)$ のままであるが、一方、ブラッグ反射構造としての1周期はそれぞれ4つずつの分極反転領域および非分極反転領域から構成される長さ $2 \times (4l) = 4\Lambda$ であり、いわゆる超格子構造となっている。従って、この実施例ではQPM条件の4周期がD

【発明の効果】この発明の光第2高調波発生装置によれば、DBR条件を満足する周期的分極反転構造を超周期構造としたので、DBR条件を緩和することができる。その結果、SHG効率の高いS-QPM SHG装置を従来よりも容易に得ることができる。

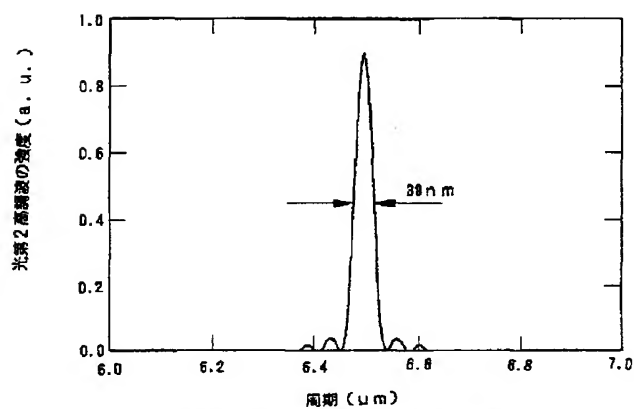
8

## 26:KTP基板

Figure 1 is a perspective view of a QPM SHG device. It shows a substrate 10 with a QPM layer 12 on top. The QPM layer has a periodic structure with period A. An input beam with frequency  $\omega$  enters from the left, and an output beam with frequency  $2\omega$  exits to the right. The top surface is labeled 'QPMSHG素子'.

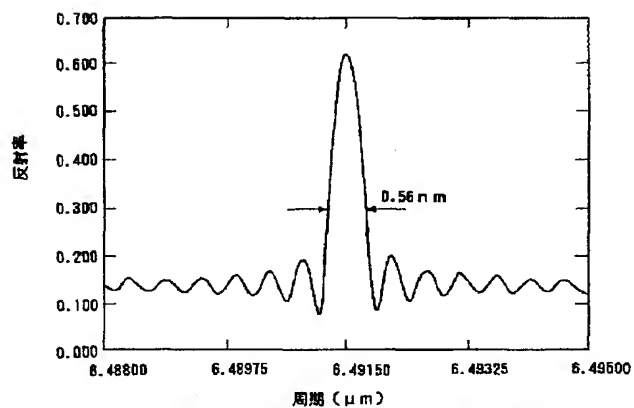
従来  $\text{LiNbO}_3$  による QPM SHG 素子

【図2】



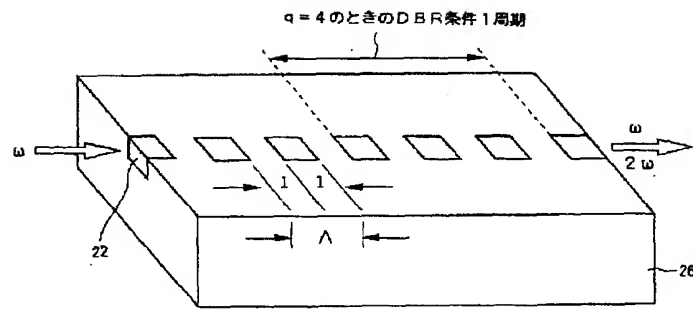
屈折率分布構造の周期とQPM素子の変換効率との関係

【図3】



屈折率分布構造の周期とDBRの反射率との関係

【図5】



実形例